Global radiation estimation using typical daily meteorological information for Saudi Arabia

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Solar radiation estimation plays an important role in solar related applications. In such applications, it is crucial to utilize some methodology for global radiation estimation in the absence of measured data. Using typical daily meteorological information was the objective of this study. Daily temperature range and daily amount of cloud in relation to global daily solar radiation was adapted and evaluated under Saudi Arabia conditions. This relation gave reasonable estimation of global radiation with correlation coefficients above 0.9. Model parameters were developed for ten stations throughout Saudi Arabia.

يلعب تقدير شدة الإشعاع الشمسي الكلي الساقط على سطح أفقي دورا مهما في كثير من التطبيقات المتعلقة بالطاقة الشمسية. ويبدو ذو أهمية كبيرة في مثل هذه التطبيقات إيجاد وسيلة لهذا التقدير في غياب القياس الفعلي لشدة الإشعاع الشمسي الكلي. تهدف هذه الدراسة إلى استخدام بيانات الأرصاد الجوية اليومية المعتادة لتقدير شدة الإشعاع الشمسي الكلي اليومي. تم تقييم العلاقة بين المدى اليومي لدرجات الحرارة و كمية الغيوم اليومية و ما يقابلها من شدة الإشعاع الشمسي اليومي الكلي تحت ظروف المملكة العربية السعودية. أعطت هذه العلاقة مستوى مقبول من الدقة و بمعامل ارتباط يزيد على٠,٩. تم تحديد العناصر الثابتة للنموذج الرياضي المقترح لعشر محطات رصد عبر المملكة العربية السعودية.

Keywords: Solar radiation, Modeling, Solar radiation estimation

1. Introduction

Solar radiation estimation by various methodologies represents valuable source of radiation information in the absence of measurement. Indeed, solar radiation measuring stations are limited in number and in the reliability of measured information. Solar radiation may be calculated using the methods according to [1,2] for clear sky condition. In spite of the importance of such methods, real condition affects the solar radiation received by the surface greatly. In solar systems performance evaluation or energy use analysis, real conditions must be represented correctly in order to produce reliable information.

Modeling of solar radiation may be accomplished using various methodologies that vary in the basic concept upon which model relies, type and number of data needed for model production and finally the extent of data needed to produce valuable results.

One of the early models is the Angstrom model [3], which relies on the correlation between sunshine duration and global solar radiation. This approach was used by many researchers [4-7]. Sunshine duration recording is not typically available in standard meteorological information and it is not always available from solar recording stations. This case led to the need to look for other model forms that may be applied using commonly available daily weather information. Daily temperature range was used by [8-10]. Daily precipitation was used by [8] and cloud cover by [11-13].

The model postulated by [3] and modified by [14] to its present form may be represented as:

$$H = H_o\left(\alpha + \beta \frac{n}{D}\right). \quad (1)$$

Where H is the daily global radiation (MJ m^{-2} d^{-1}), n the daily sunshine duration (hr), D the astronomical day length, and h, α and β are empirical constants. The two constants have been derived for various locations throughout the world [15-17]. For Saudi Arabia [18], was generated using sunshine duration measurement of several stations. Since then, little effort was published regarding solar radiation estimation. Locally, [4] presented some models for estimation global and diffuse radiation at Qassim, Saudi Arabia. At Dhahran, Saudi Arabia [19] presented a model for global radiation estimation. This study was based on upper air meteorological data collected at Dhahran for one year. Such model application is limited by the availability of upper air meteorological data that is not normal practice in most weather stations.

The objective of this study was to develop simple model for daily global radiation estimation using typical daily meteorological factors for Saudi Arabia.

2. Methods

To estimate daily global solar radiation, simple model correlating the daily global radiation to daily ambient range was used by [9, 20]. The work by [20] introduced daily mean cloud cover to the model, which gave better estimation. Analysis of cloud cover and solar radiation showed a non-linear relationship according to [21, 22]. Square root equations were found suitable for global radiation estimation using cloud cover. The study by [19] used combination of [20,9] models for estimation of global radiation for most European countries. This method was adapted in this study with the following model:

$$H = H_o\left(a\sqrt{T_{max} - T_{min}} + b\sqrt{(1 - C_w/8)}\right) + c . \quad (2)$$

Where T_{max} is the maximum daily temperature, T_{min} is the minimum daily temperature, C_w is the mean of total cloud cover of the daytime observations (octa) and a, b and c are empirical constants.

Data were obtained from daily meteorological report from Meteorology & Environmental Protection Administration (MEPA) in Saudi Arabia in addition to solar radiation measurements for ten stations. These data were collected during 1996 and 1997. Table 1 gives some information a bout stations locations.

Model development were carried out using least square method to fined the best fit of the model and to obtain the empirical factors according to location. To evaluate the model accuracy; the Root Mean Square Error (RMSE) and the Mean Bias error (MBE).

$$RMSE = \sqrt{\frac{\Sigma(H - \hat{H})^2}{N_{obs}}} , \quad (3)$$

$$MBE = \frac{\Sigma(H - \hat{H})}{N_{obs}} . \quad (4)$$

Where H is the observed daily global solar radiation MJ m^{-2} d^{-1}, $\hat{H}$ is the estimated daily global solar radiation and N_{obs} is the number of observations.

3. Results and discussion

Carrying out the presented methodology produced the results shown in table 2. In this table, statistical results of proposed model development is arranged according to location. Empirical factors a, b and c are presented

Table 1
Stations geographical information

WMO #	Location	Latitude	Longitude	Elevation (m)
403610	Al-Jouf	29° 56' N	40° 04' E	689
403730	Hafr Al-batin	28° 20' N	46° 07' E	360
403750	Tabuk	28° 24' N	36° 35' E	776
404050	Qassim	26° 18' N	43° 51' E	650
404300	Madinah	24° 39' N	39° 39' E	647
404370	Riyadh	24° 56' N	46° 43' E	612
410610	Wadi Al dawaser	20° 30' N	45° 12' E	622
411120	Abha	18° 14' N	42° 23' E	2093
411360	Sharurah	17° 30' N	47° 07' E	900
411400	Gizan	16° 54' N	42° 35' E	3

Table 2
Regression coefficients a, b and c, standard error SE and correlation coefficient r^2 Of the daily global radiation for the proposed model

	Proposed model						
Location	A	SE	B	SE	C	SE	r^2
Al-Jouf	0.0652	0.0046	0.466	0.0182	0.298	0.0245	0.96
Hafr Al-Batin	0.0596	0.0085	0.461	0.0354	0.624	0.0493	0.84
Tabuk	0.0534	0.0053	0.497	0.0233	0.512	0.0310	0.94
Qassim	0.0926	0.0084	0.334	0.0352	-0.389	0.0525	0.84
Madinah	0.0527	0.0064	0.548	0.0245	-1.454	0.0389	0.92
Riyadh	0.0800	0.0055	0.365	0.0223	0.742	0.0356	0.91
Wadi Al Dawaser	0.0597	0.0056	0.416	0.0240	1.225	0.0389	0.89
Abha	0.0026	0.0115	0.709	0.0545	1.079	0.0886	0.86
Sharurah	0.0500	0.0047	0.445	0.0219	1.475	0.0485	0.85
Gizan	0.0451	0.0084	0.544	0.0259	0.571	0.0649	0.89

Table 3
Performance statistics summary with mean daily measured radiation

Location	Mean (KJ/m²)	MBE	RMSE
AL-JOUF	21206	-0.0000	1.39
HAFR AL-BATIN	21187	-0.0010	2.70
TABUK	21997	0.0013	1.55
QASSIM	20911	0.0018	2.85
MADINAH	21761	-0.0016	1.76
RIYADH	21196	-0.0003	1.88
WADI AL DAWASER	22261	-0.0008	1.47
ABHA	19782	0.1960	2.90
SHARURAH	23256	-0.0008	1.40
GIZAN	20770	0.0007	1.86

with the corresponding Standard Error (SE). The Coefficient of determination is given in the last column. Comparing the standard errors and correlation coefficients shown in table 2 with results given for many European countries reported by [20], the performance of the model under Saudi Arabian conditions was equal or better. It is apparent that r^2 values approaches 0.9 or higher for most stations. Similar conclusion may be realized when comparing presented model accuracy with results reported in Saudi Solar Atlas, which was based on Angstrom model and its relation to sunshine period.

Table 3 shows the results of model application for Saudi Arabia and the corresponding accuracy measures (RMSE and MBE). Comparing these results to similar study throughout Europe with relatively similar size of data, the proposed model showed less deviation than that was reported by [20]. Indeed, the percentage of errors was mostly within 10% of measured daily global radiation. In fact ASHRAE method can deviate by 15% on normal clear sky day as it is noted in the Handbook of Fundamentals.

Fig. 1 represents a plotting of observed monthly average daily global radiation versus the estimated monthly average daily global radiation for various stations. High correlation coefficient of 0.983 was possible using the proposed model. Fig 2 shows the observed monthly total global solar radiation against estimated monthly total global solar radiation. Acceptable level of correlation coefficient of 0.98 was possible. This means that most correlating factors were included within the model and no seasonal pattern is present.

Fig. 3 presents the empirical factor (a) distribution throughout Saudi Arabia. Fig 4 shows the distribution of (b) factor and fig. 5 gives the distribution of (c) factor using linear interpolation. These graphs represent the results as a function of longitude and latitude. From fig. 3, factor (a) ranged from 0.02 at the mountain region in southwest to 0.09 at the northwest area. In fig 4, factor (b) takes values between 0.62 at southwest to 0.34 at

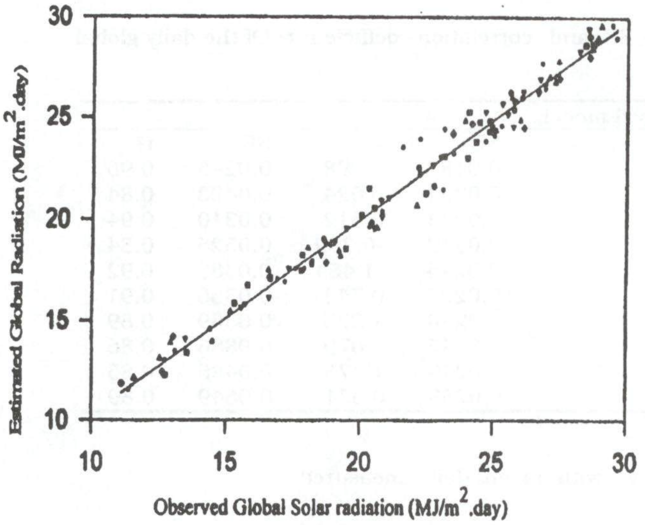

Fig. 1. Observed monthly average daily global radiation versus estimated monthly average daily global radiation for Saudi Arabia.

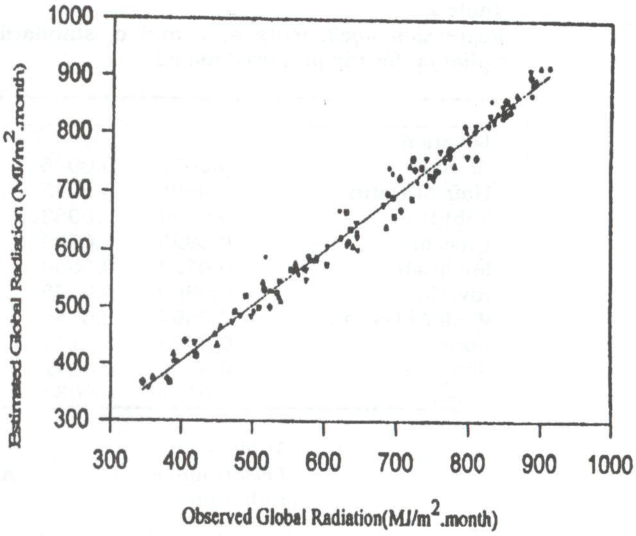

Fig. 2. Observed monthly total global radiations versus estimated monthly total global radiation.

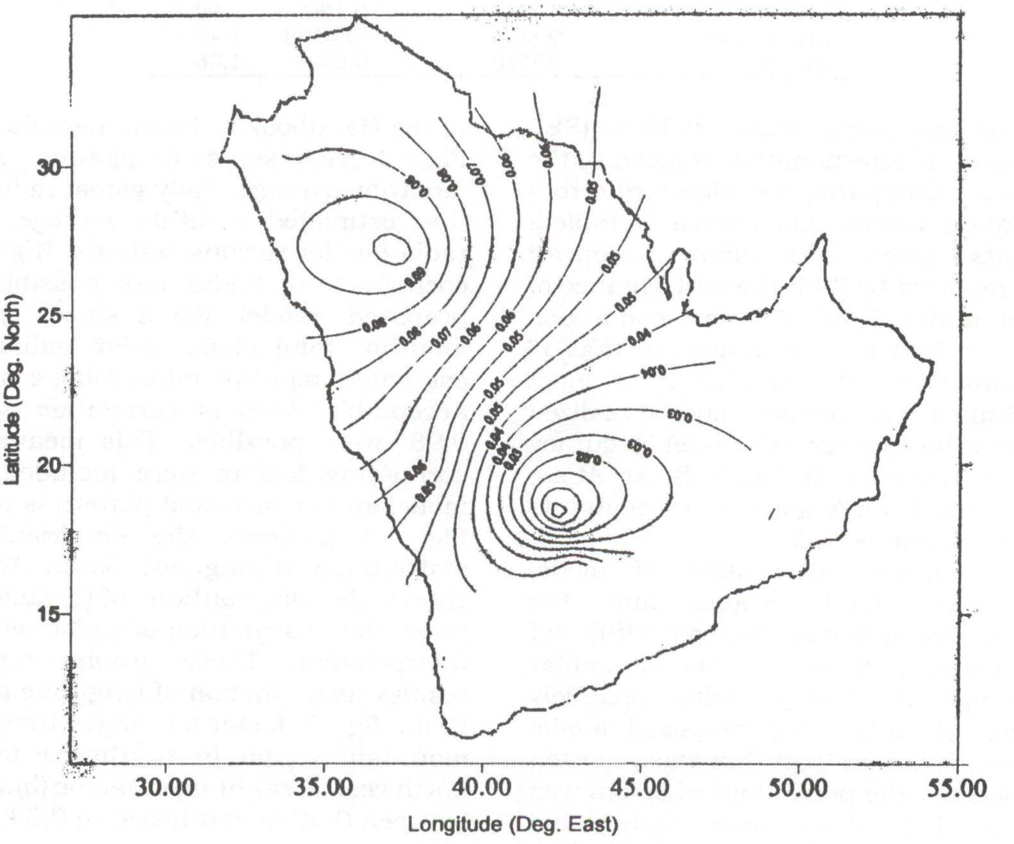

Fig. 3. Empirical factors (a) distribution throughout Saudi Arabia.

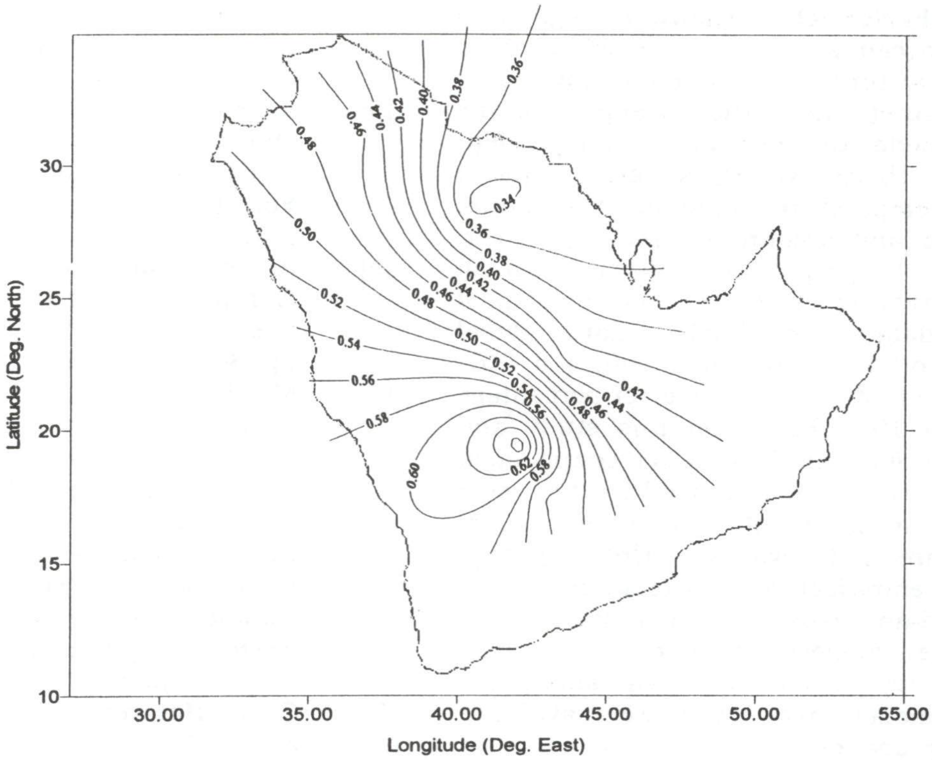

Fig. 4. Empirical factor (b) distributions throughout Saudi Arabia..

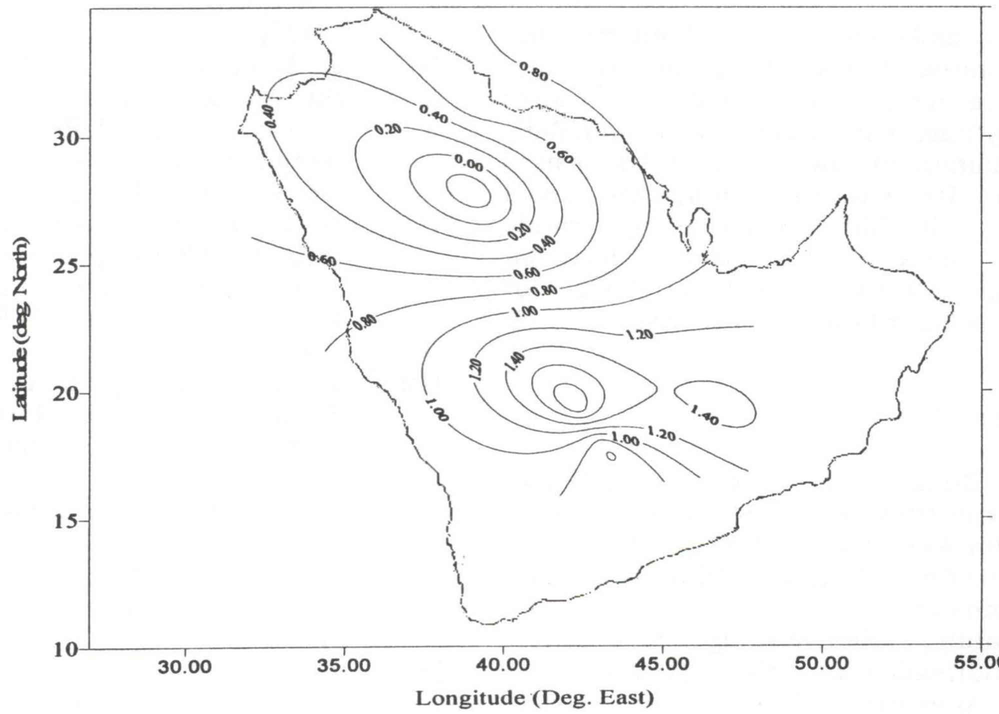

Fig. 5. Empirical factor (c) distributions throughout Saudi Arabia.

northeast. Factor (c) is shown in fig. 5 and ranged between zeros at the north area to around 1.5 at southern area. Finally, it should be emphasized that, the strength of the proposed model depends on its independent variables. These variables are ambient maximum temperature and ambient minimum temperature and amount of total sky cover. These factors are always available from all standard weather stations and their past recorded data. Accordingly, daily global radiation could be estimated within a 90% accuracy and at worst case error percentage may reach 15%. Based on this study and similar described studies, it is recommended to use of the proposed model when ever accurate measurement of daily global radiation are not available. Unfortunately, driving this empirical model was dependent on historical data, which in turn depends on locality; nevertheless, similar geographical locations may serve as an alternative whenever model parameters were available from similar location.

4. Conclusions

Appling daily meteorological information; daily maximum temperature, daily minimum temperature and the mean of total cloud cover of the daytime, can be used to estimate daily global radiation in Saudi Arabia. The results are comparable with using Angstrom model with the simplification of using readily available data of standard recorded meteorological factors. Model was tested for ten stations distributed evenly within Saudi Arabia.

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